Pennsylvania Horticultural Society

Planted Tree Re-Inventory Report:

Survival, Condition, and Benefits of Recently Planted Trees

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Funders:
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Background

The Bloomington Urban Forestry Research Group (BUFRG) at Indiana University was funded by the U.S. Forest Service's National Urban and Community Forestry Advisory Council (NUCFAC) to conduct a five-city study of tree planting projects supported by nonprofit organizations in urban settings. BUFRG partnered with Trees Atlanta, The Greening of Detroit, Keep Indianapolis Beautiful, Inc., the Pennsylvania Horticultural Society, Forest ReLeaf of Missouri, and the Alliance for Community Trees to conduct this research. The study included a re-inventory of trees planted in projects funded by these nonprofits from 2009 to 2011. This report presents the results of the re-inventory data analysis for the Pennsylvania Horticultural Society, with emphasis on benefit estimates generated using i-Tree Streets.

Summary of Results

Teams of volunteers, supervised by the Pennsylvania Horticultural Society (PHS), re-inventoried 1,742 trees in Philadelphia in June, July, and August of 2014. These trees were selected from a list of 5,366 trees planted by PHS from 2009 to 2011. At the time of re-inventory, 59% of these recently planted trees had survived. Highlights of the tree analysis are:

- Most (53% of) re-inventoried trees were found to be in good condition.
- Average diameter at breast height (DBH) of surviving trees was 6.4 cm (2.5 inches).
- Re-inventoried trees provide almost $16,000 in total annual benefits, an average of $15.70 per tree.
- Re-inventoried trees provide almost 5,500 m^2 (59,000 ft^2) of canopy cover.
- Japanese tree lilac (*Syringa reticulata*) was the most common species of surviving re-inventoried trees (Figure 1).
- Maple (*Acer*) was the most common genus of surviving re-inventoried trees (Figure 2).
- Japanese tree lilacs provide the most canopy cover.
- Red maples (*Acer rubrum*) provide the most total annual benefits.
- All 5,366 trees planted from 2009 to 2011 have a species composition similar to the re-inventoried trees; if all trees planted from 2009 to 2011 had the same average DBH and mortality rates as the re-inventoried trees, they would provide approximately $50,000 in total annual benefits.

Species Distribution

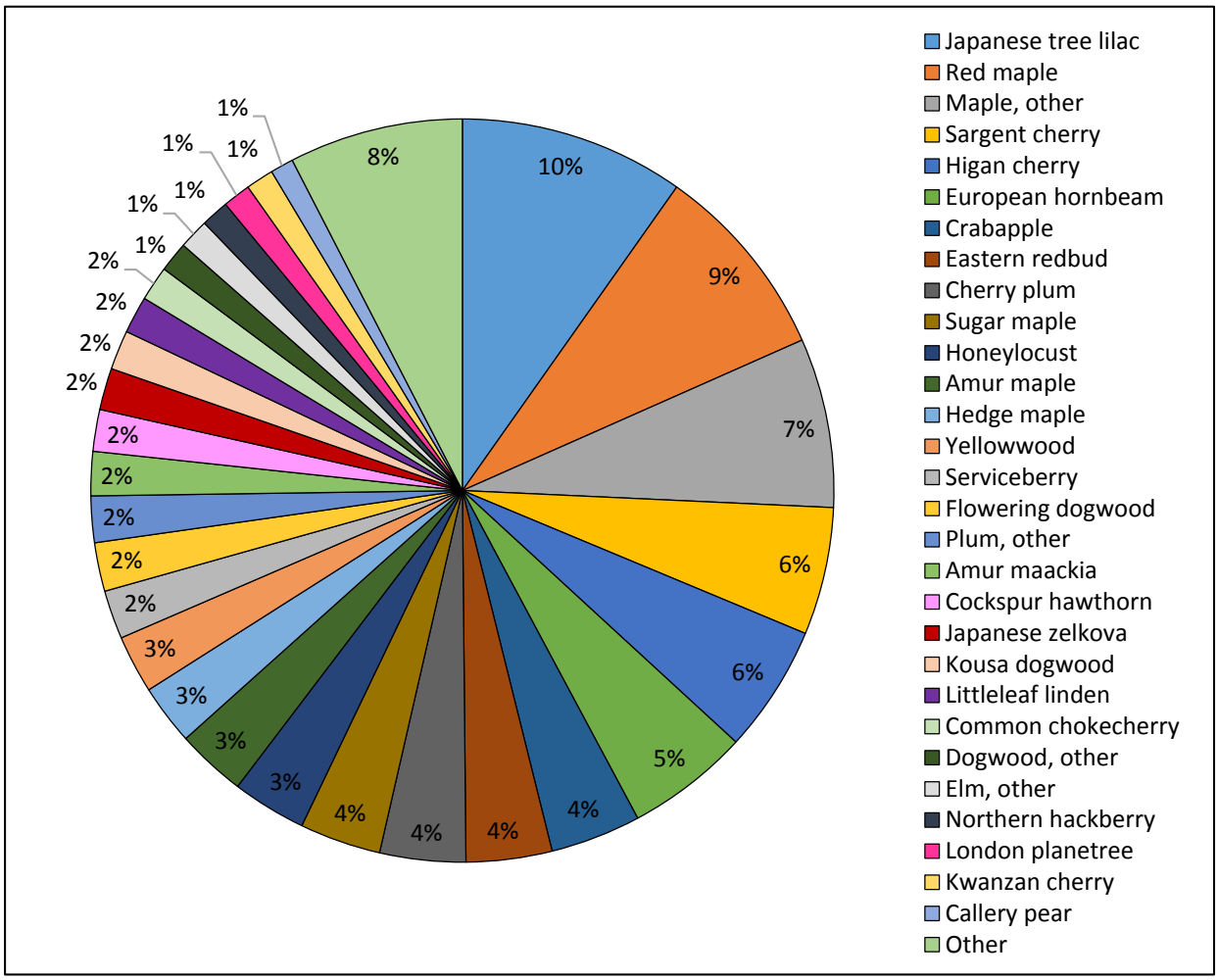

Figure 1. Species distribution of surviving re-inventoried trees planted by PHS from 2009 to 2011. "Other" includes species that each make up less than 1% of the population – see Appendix Table A1 for a full list of species.

Genus Distribution

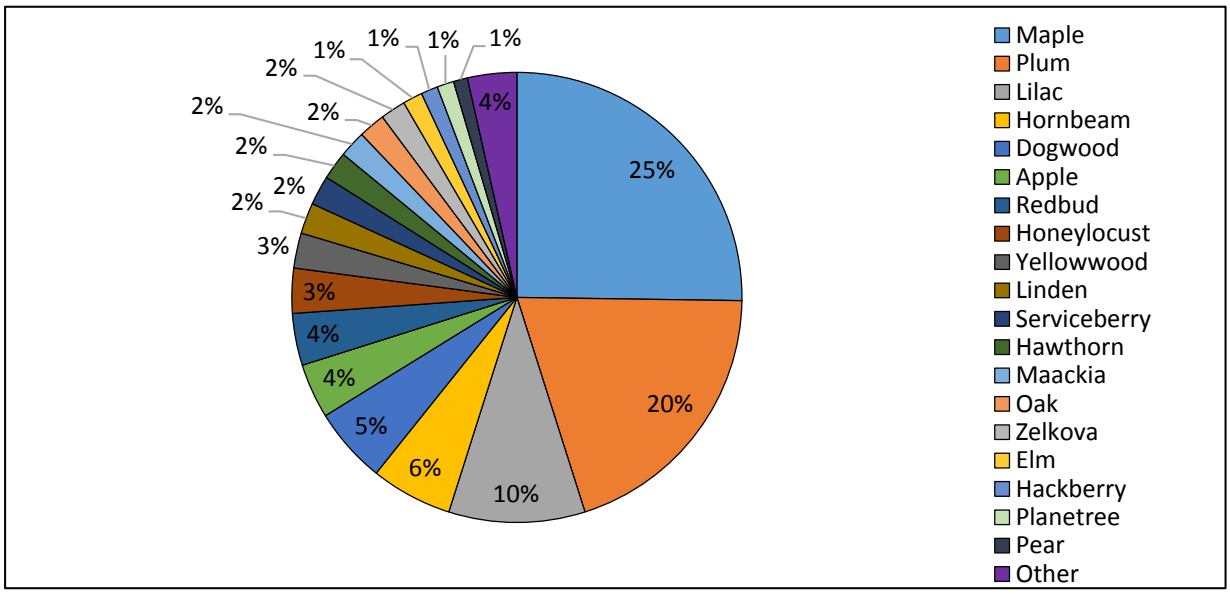

Figure 2. Genus distribution of surviving re-inventoried trees planted by PHS from 2009 to 2011. "Other" includes genera that each make up less than 1% of the population.

Size Distribution

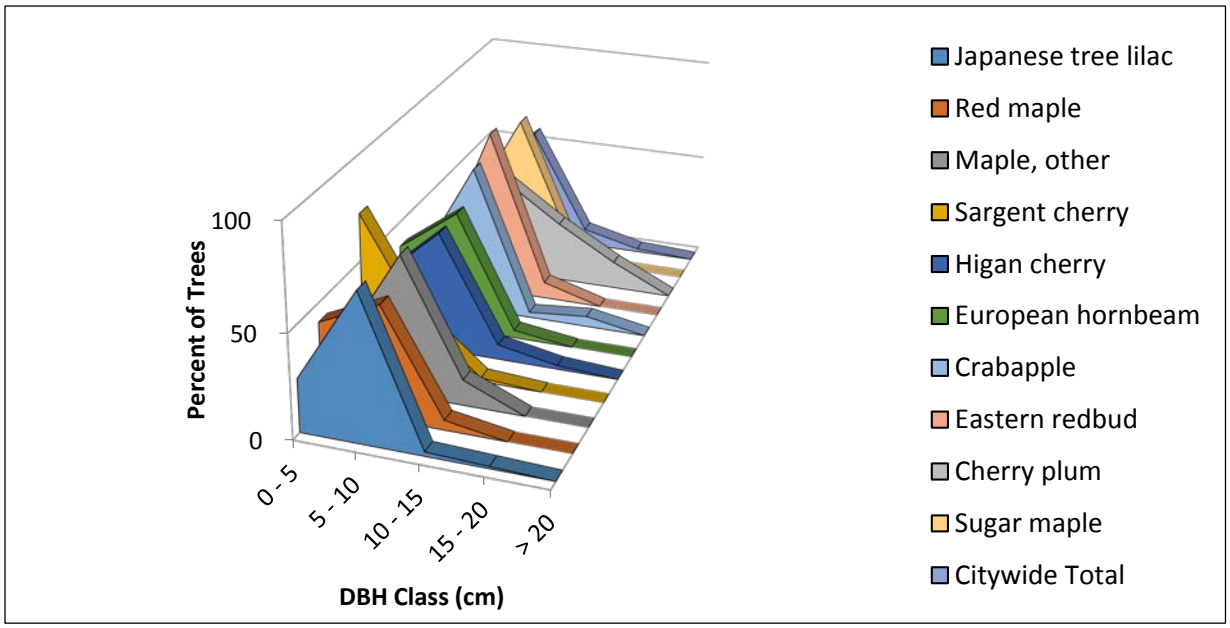

Figure 3. Size distributions of the ten most common surviving tree species.

One third (33%) of surviving re-inventoried trees were in the 0-5 cm (0-2 in.) size class, 57% were in the 5-10 cm (2-4 in.) size class, and 10% had a DBH of 10 cm (4 in.) or greater (Figure 3). More than half of re-inventoried Sargent cherry trees (*Prunus sargentii*) were in the 0-5 cm (0-2 in.) size class. No trees in the re-inventory sample were larger than 25 cm (9.8 inches).

Overall Condition

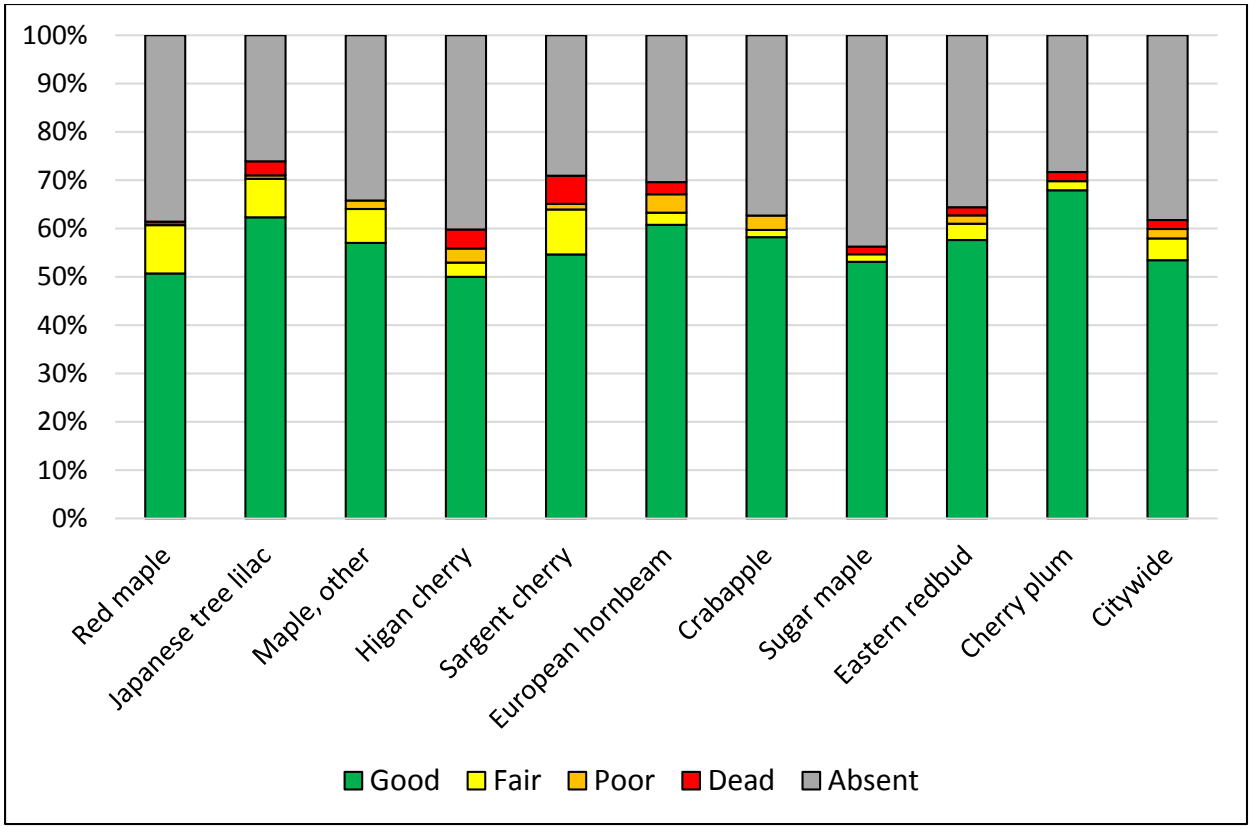

Figure 4. Frequency of overall condition ratings of the ten most common re-inventoried tree species.

Overall condition of living trees was rated in three categories: good, fair, and poor (Table 1). Fifty-three percent of all re-inventoried trees were in good condition, 5% were in fair condition, 2% were in poor condition, 2% were dead, and 38% were absent (Figure 4). Overall condition ratings varied among species; only 50% of re-inventoried Higan cherry (*Prunus subhirtella*) trees were in good condition, while 68% of re-inventoried cherry plums (*Prunus cerasifera*) were in good condition.

Table 1. Explanation of overall condition ratings. From Vogt et al. 2014.

Rating	Explanation
Good	Full canopy, minimal to no mechanical damage to trunk, no branch dieback over 5 cm (2”) in diameter, no suckering (root or water sprouts), form is characteristic of species.
Fair	Thinning canopy, new growth in medium to low amounts, tree may be stunted, significant mechanical damage to trunk (new or old), insect/disease is visibly affecting the tree, form not representative of species, premature fall coloring on foliage, needs training pruning.
Poor	Tree is declining, visible dead branches over 5 cm (2”) in diameter in canopy, significant dieback of other branches in inner and outer canopy, severe mechanical damage to trunk usually including decay from damage, new foliage is small, stunted or minimum amount of new growth, needs priority pruning of dead wood.

Leaf Area, Canopy Cover, and Benefit Estimates from i-Tree Streets

Quantification of the canopy cover and other benefits provided by trees can help justify the costs of tree plantings. We used i-Tree Streets, a program developed by the U.S. Forest Service and Davey Resource Group, to estimate the total leaf area, canopy cover, and benefits provided by the re-inventoried trees. i-Tree Streets takes into account the species and size class of each tree in calculating leaf area and canopy cover and incorporates the energy costs and climate of the region in calculating benefits.

Leaf Area and Canopy Cover Estimates:

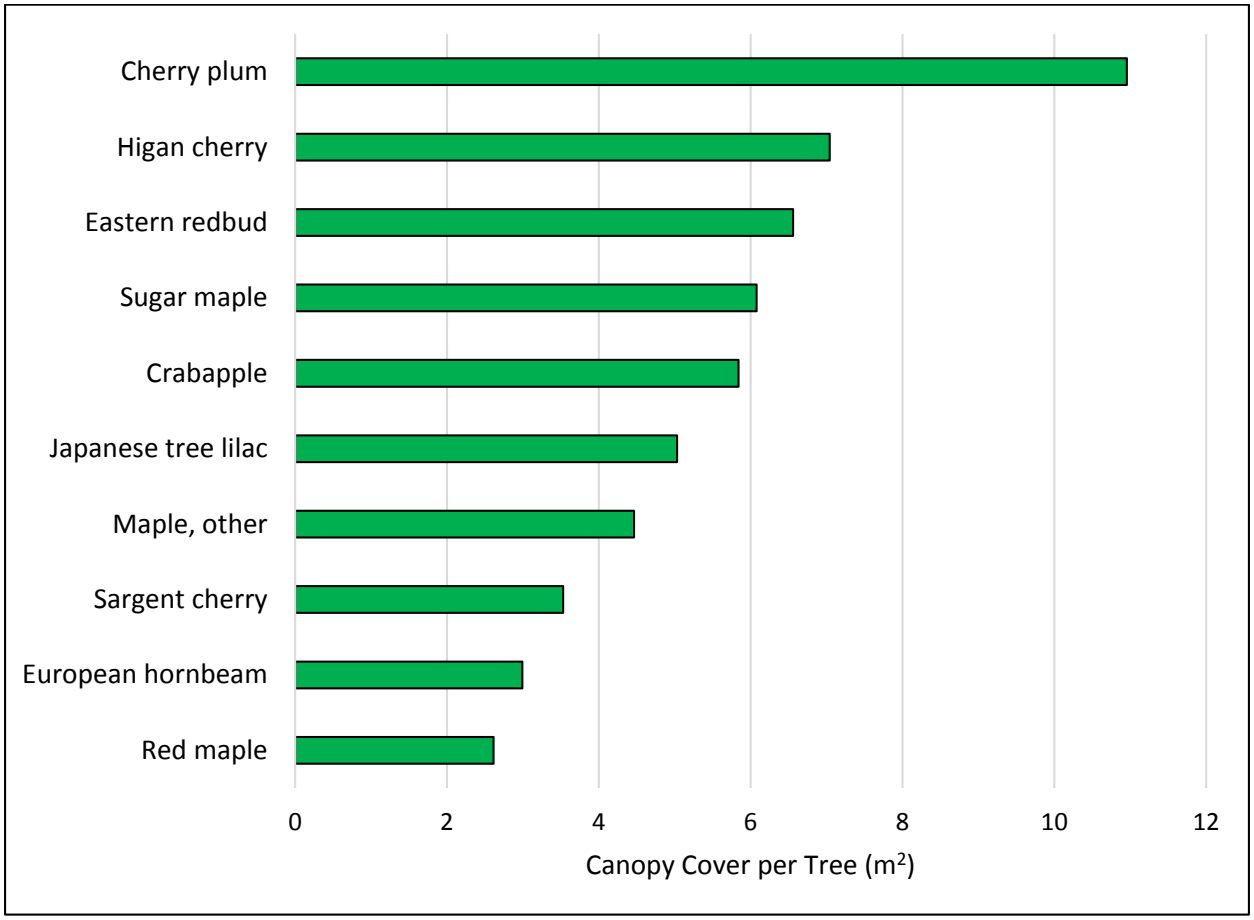

Figure 5. Average estimated canopy cover per tree (m^2) of the ten most common surviving tree species.

Re-inventoried trees provide 5,500 m^2 (59,000 ft^2) of canopy cover and 14,000 m^2 (150,000 ft^2) of total leaf area. Canopy cover is the area of ground shaded by the tree, while leaf area is the total surface area of all the leaves in a tree's crown. Leaf area can be significantly larger than canopy cover because additional vertical layers of leaves increase leaf area without increasing canopy cover. The average re-inventoried tree currently provides 5.5 m^2 (60 ft^2) of canopy cover.

Of the ten most common surviving re-inventoried tree species, cherry plums provide the most canopy cover per tree, while red maples provide the least canopy cover per tree (Figure 5).

Benefit Estimates:

i-Tree Streets estimates benefits in five categories: energy, CO_2, air quality, stormwater, and aesthetic/other benefits. Energy benefits are the reduced building heating and cooling costs provided by the tree. CO_2 benefits value the carbon sequestered by the tree and CO_2 emissions avoided due to reduced energy usage. Air quality benefits take into account ozone, NO_2, SO_2, PM_{10}, and VOC uptake and avoidance. Stormwater benefits quantify the value of reduced stormwater runoff due to rain interception by the tree. Aesthetic benefits take into account the increase in property value associated with the tree. The method used to calculate benefit estimates is detailed by McPherson and colleagues (2007).

Table 2. Estimated total annual benefits provided by re-inventoried trees in Philadelphia.

Benefit Type	Total Benefits	$/Tree	Percent of Total Benefits
Energy	$3,074	$3.10	20%
CO_2	$129	$0.13	1%
Air Quality	$958	$0.97	6%
Stormwater	$982	$0.99	6%
Aesthetic/Other	$10,412	$10.51	67%
Total Benefits	$15,556	$15.70	100%

Most (67%) of the estimated benefits provided by the re-inventoried trees are aesthetic (Table 2; Figure 6). We expect the aesthetic benefits to become relatively less important over time as the trees grow larger and contribute more to energy, stormwater, CO_2, and air quality benefits. Currently, red maples (*Acer rubrum*) contribute most to the total estimated benefits (Figure 7). See Appendix Table A2 for a full list of benefits per tree, by type, provided by each re-inventoried species.

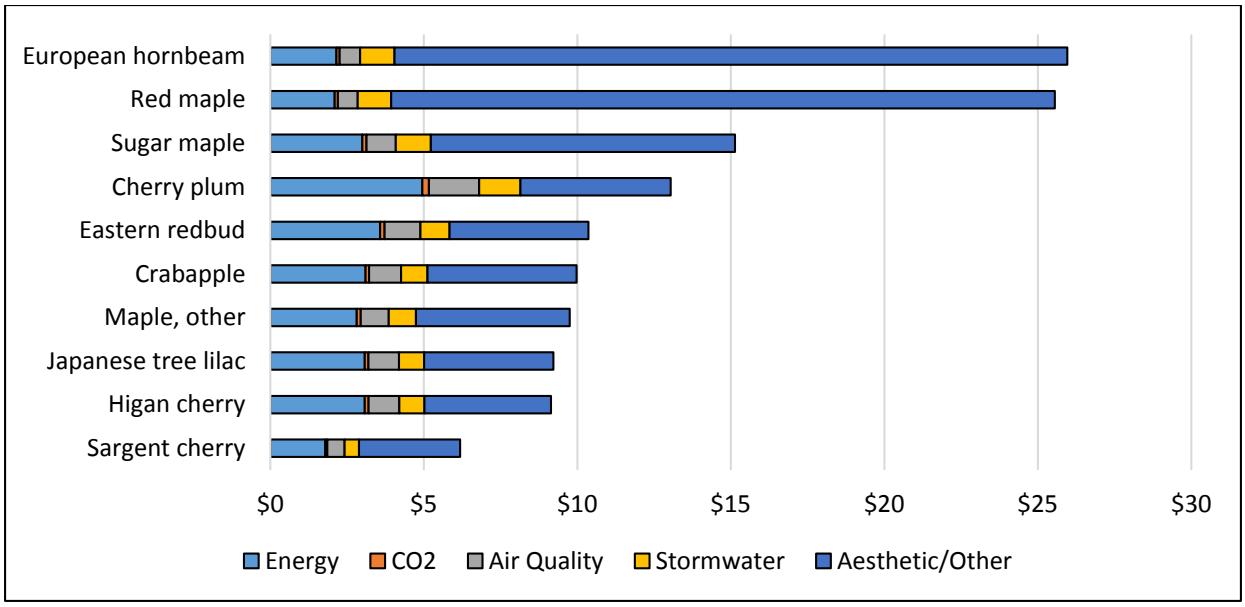

Figure 6. Estimated annual benefits per tree, by type, provided by the ten most common surviving tree species.

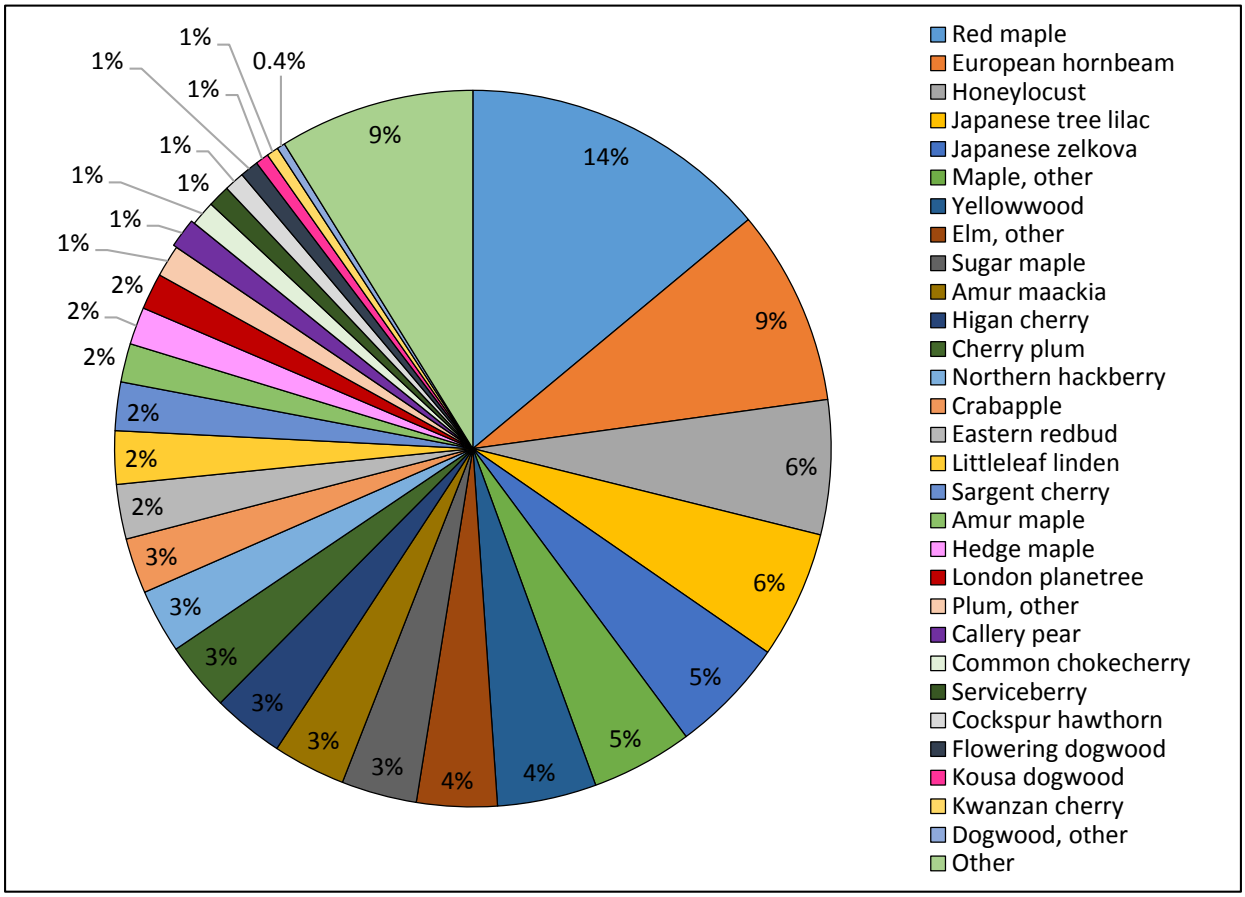

Figure 7. Each species' contribution to estimated total annual benefits. Red maples provide 14% of estimated total annual benefits though they make up only 9% of total trees.

Tree Benefits: A Closer Look

Energy Benefits:

Re-inventoried trees provide an estimated $3,074 in annual energy benefits (Table 2). Cherry plums (*Prunus cerasifera*) contribute more energy benefits per tree than other species (Figure 8). The top three contributors to estimated energy benefits are Japanese tree lilacs (10% of total energy benefits), Japanese zelkovas (7% of total energy benefits), and "other" maples* (7% of total energy benefits).

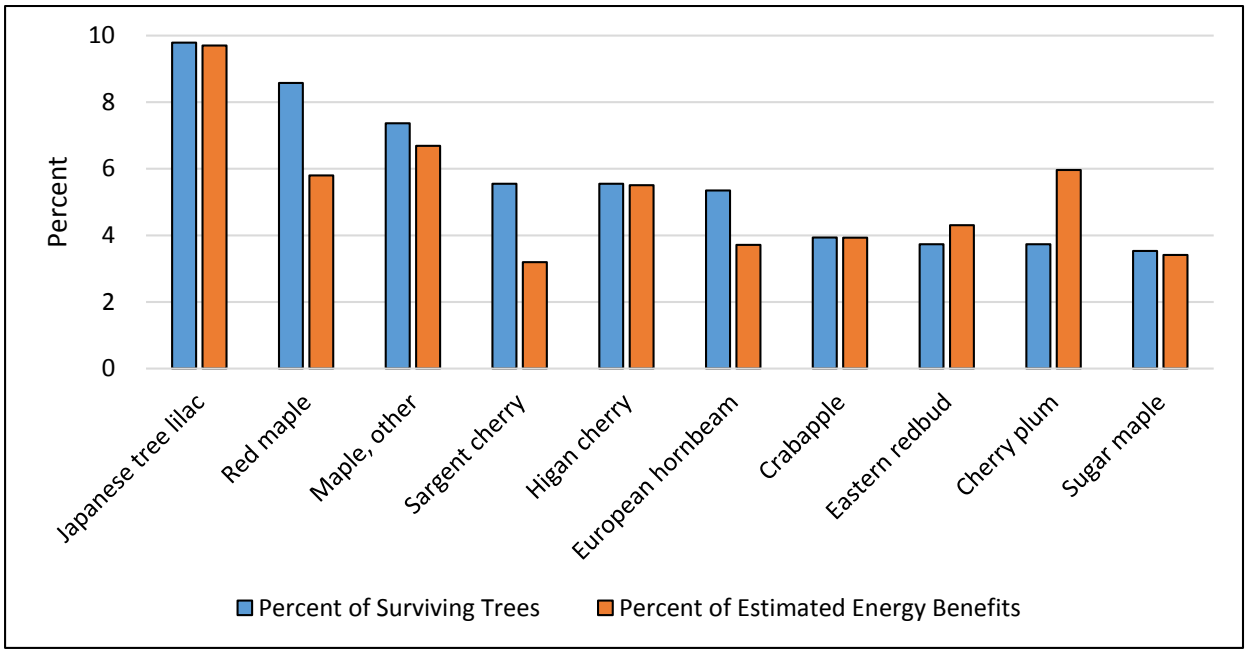

Figure 8. Percent of surviving trees compared to percent of estimated total annual energy benefits provided by the ten most common tree species.

CO_2 Benefits:

All together, re-inventoried trees provide an estimated $129 in annual CO_2 benefits, which corresponds to 18,000 kg of CO_2 sequestered or avoided annually. Sequestered CO_2 refers to the volume of carbon stored in the tree as it grows larger each year, while avoided CO_2 refers to the carbon emissions avoided through reduced heating and cooling energy usage. Re-inventoried trees have been in the ground only 3-5 years and are therefore still relatively small in size, and small trees put on (sequester) less additional volume per year than larger trees.

All Japanese tree lilacs in the re-inventory sample (97 trees with an average DBH of 2.5 in) sequester or avoid 1,600 kg of CO_2 (worth $12) each year. All "other" maples in the re-inventory sample (73 trees with an average DBH of 2.7 in) sequester or avoid 1,270 kg of CO_2 (worth $9) each year.

*Maple, other includes *Acer griseum, Acer miyabei, Acer tataricum, Acer truncatum,* and *Acer x freemanii* 'Armstrong'

Air Quality Benefits:

All together, re-inventoried trees provide an estimated $958 in annual air quality benefits, representing uptake or avoidance of 18 kg of ozone, 44 kg of NO_2, 11 kg of PM_{10}, and 19 kg of SO_2 each year. Trees reduce air pollution directly by absorbing gaseous pollutants and intercepting small particles and indirectly by reducing energy usage, thereby reducing emissions from power plants (McPherson et al. 2007). These functions are dependent on tree size and leaf area, so annual air quality benefits will increase as the trees grow larger. Japanese tree lilacs, "other" maples, and cherry plums contribute most to estimated air quality benefits at 10%, 7%, and 6% of total air quality benefits, respectively.

Stormwater Benefits:

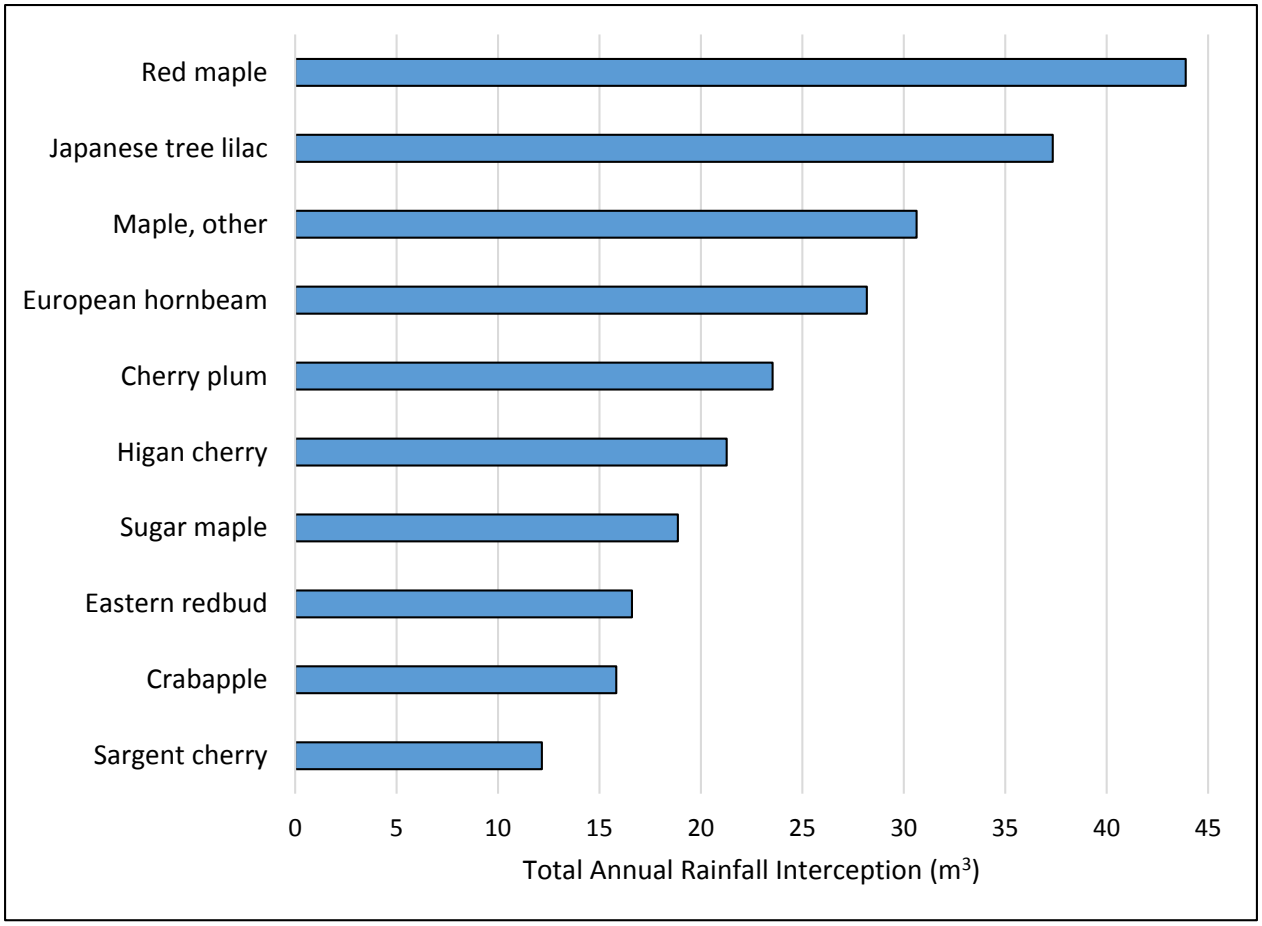

Figure 9. Estimated total rainfall (m^3) intercepted annually by the ten most abundant re-inventoried trees.

Re-inventoried trees intercept an estimated 465 m^3 (16,400 ft^3) of rainfall each year and provide $982 in annual stormwater benefits. Red maples provide 9% of total stormwater benefits, collectively intercepting 44 m^3 (1,550 ft^3) of rainfall per year, more than 0.5 m^3 (18 ft^3) per tree (Figure 9).

Aesthetic/Property Value Benefits:

Most of the benefits provided by the re-inventoried trees are aesthetic benefits, quantified by an increase in property value. Aesthetic/property value benefit estimates in i-Tree Streets are dependent on tree size, but do not take into account whether a tree flowers or not (see Anderson and Cordell 1988 for supporting research). Red maples contribute most to total aesthetic benefits (Table 3). The total annual aesthetic value of all re-inventoried trees was $10,400, an average of $10.50 per tree.

Table 3. Summary of the ten tree species that contribute most to estimated annual aesthetic benefits.

Species	Average Aesthetic Benefits per Tree	Total Aesthetic Benefits	Percent of Total Aesthetic Benefits
Elm, other	$31	$401	4%
Japanese zelkova	$28	$506	5%
Yellowwood	$23	$569	5%
Honeylocust	$22	$711	7%
Amur maackia	$22	$418	4%
European hornbeam	$22	$1,161	11%
Red maple	$22	$1,837	18%
Sugar maple	$10	$347	3%
Maple, other	$5	$366	4%
Japanese tree lilac	$4	$409	4%

Structural/Replacement Value

A tree's structural (also called replacement) value is the amount it would cost to replace the planted tree and depends on the tree's species, size, and condition rating. The total replacement value of the surviving re-inventoried trees is $277,000. Japanese tree lilacs and "other" maples contribute most to the replacement value at $27,000 and $22,000, respectively. Assuming each tree costs $155 to plant (Peper et al. 2009), the initial cost of the re-inventoried trees would be $270,000. At this price, the value of trees planted from 2009 to 2011 exceed the costs after only 3-5 years of growth.

How Annual Benefits Change over a Tree's Lifetime

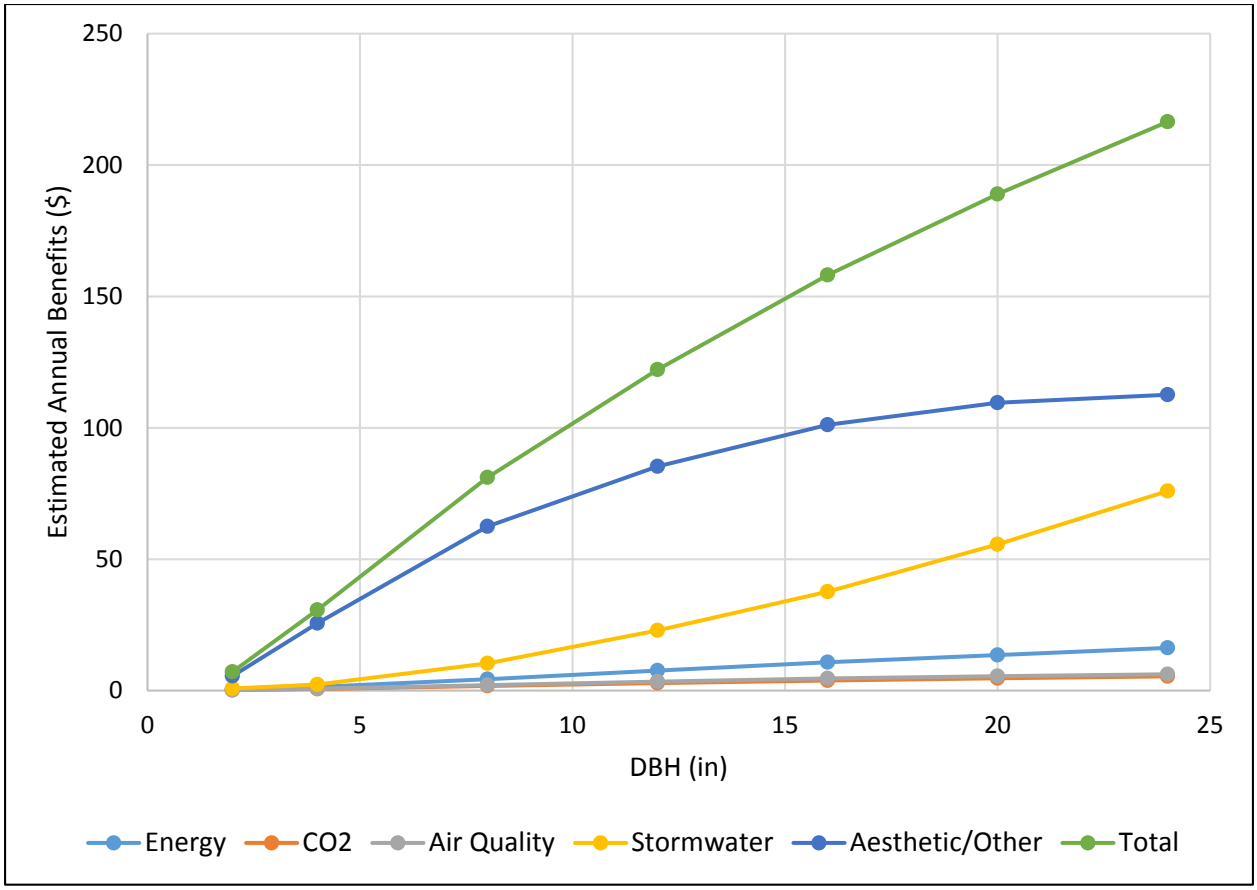

Figure 10. Estimated annual benefits of a sugar maple at different sizes up to 24 inches DBH in the South climate region.

We expect annual benefits to change over the lifetime of a tree in two ways: the total benefits increase, and the aesthetic benefits become relatively less important as stormwater and other benefit types become more important. Benefit types that are related to tree growth, such as CO_2 benefits, decline as the tree's growth slows. Energy, CO_2, and air quality benefits remain small relative to other benefit types because of the low cost of electricity and natural gas, carbon emissions, and air pollutants. i-Tree uses growth models based on urban tree data to predict how a tree's height, crown diameter, and leaf area will change over its lifetime (McPherson et al. 2007). For the hypothetical tree modeled in Figure 10, 52% of total benefits are aesthetic benefits, 35% are stormwater benefits, 7% are energy benefits, 3% are air quality benefits, and 3% are CO_2 benefits at 24 inches DBH.

Resources

Anderson, L.M. and Cordell, H.K. 1988. Influence of trees on residential property values in Athens, Georgia (U.S.A.): a survey based on actual sales prices. Landscape and Urban Planning 15: 153-164. Available from http://www.srs.fs.usda.gov/pubs/ja/ja_anderson003.pdf.

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Vogt, J.M., Mincey, S.K., Fischer, B.C., and Patterson, M. 2014. Planted tree re-inventory protocol. Version 1.1. Bloomington, IN: Bloomington Urban Forestry Research Group at the Center for the Study of Institutions, Population and Environmental Change, Indiana University. Available from http://www.indiana.edu/~cipec/research/bufrg_protocol.php.

Appendix

Table A1. Scientific and common names, average DBH (inches) of surviving re-inventoried trees.

Scientific Name	Common Name	Number of Trees	Average DBH (in)
Carpinus caroliniana	American hornbeam	5	2.0
Maackia amurensis	Amur maackia	19	2.6
Acer ginnala	Amur maple	30	2.5
Taxodium distichum	Baldcypress	1	4.9
Tilia spp.	Basswood	3	3.7
Viburnum prunifolium	Blackhaw	2	3.1
Pyrus calleryana	Callery pear	10	2.8
Prunus cerasifera	Cherry plum	37	3.8
Ulmus parvifolia	Chinese elm	1	1.9
Crataegus crus-galli	Cockspur hawthorn	18	1.9
Prunus virginiana	Common chokecherry	15	5.9
Cornus mas	Cornelian cherry	3	1.4
Malus spp.	Crabapple	39	2.8
Metasequoia glyptostroboides	Dawn redwood	2	1.5
Cornus spp.	Dogwood, other*	13	1.1
Ostrya virginiana	Eastern hophornbeam	5	1.9
Cercis canadensis	Eastern redbud	37	2.7
Ulmus spp.	Elm, other*	13	4.7
Quercus robur	English oak	4	2.2
Carpinus betulus	European hornbeam	53	2.3
Cornus florida	Flowering dogwood	21	1.6
Ginkgo biloba	Ginkgo	6	1.5
Crataegus viridis	Green hawthorn	2	1.7
Acer campestre	Hedge maple	26	2.8
Prunus subhirtella	Higan cherry	55	2.6
Gleditsia triacanthos	Honeylocust	32	2.8
Styrax japonicus	Japanese snowbell	5	1.3
Syringa reticulata	Japanese tree lilac	97	2.5
Zelkova serrata	Japanese zelkova	18	3.4
Cercidiphyllum japonicum	Katsura tree	2	4.1
Gymnocladus dioicus	Kentucky coffeetree	1	1.3
Cornus kousa	Kousa dogwood	17	1.1
Prunus serrulata	Kwanzan cherry	12	2.1
Tilia cordata	Littleleaf linden	16	3.2
Platanus x acerifolia	London planetree	12	3.2
Acer spp.	Maple, other	73	2.7
Celtis occidentalis	Northern hackberry	12	2.5
Quercus rubra	Northern red oak	4	2.3
Quercus palustris	Pin oak	2	2.9

Prunus spp.	Plum, other*	20	3.1
Prunus x cistena	Purpleleaf sand cherry	3	1.4
Aesculus x carnea	Red horsechestnut	4	1.8
Acer rubrum	Red maple	85	2.2
Prunus sargentii	Sargent cherry	55	1.8
Quercus acutissima	Sawtooth oak	4	3.4
Quercus coccinea	Scarlet oak	3	2.4
Amelanchier spp.	Serviceberry	21	1.9
Tilia tomentosa	Silver linden	3	2.2
Acer pensylvanicum	Striped maple	1	2.1
Acer saccharum	Sugar maple	35	2.8
Quercus bicolor	Swamp white oak	2	2.5
Corylus colurna	Turkish hazelnut	5	2.4
Halesia diptera	Two-wing silverbell	2	2.0
Cladrastis kentukea	Yellowwood	25	2.6
Citywide Total	Citywide Total	991	2.5

*Dogwood, other includes *Cornus florida* x *kousa* 'Constellation' and *Cornus* 'Celestial'. Elm, other includes *Ulmus* 'Accolade' and *Ulmus* x 'Homestead'. Plum, other includes *Prunus campanulata, Prunus padus*, and *Prunus x hilleri.*

Table A2. Estimated energy, CO_2, air quality, stormwater, aesthetic, and total benefits per tree for surviving re-inventoried trees.

Species	Energy Benefits	CO_2 Benefits	Air Quality Benefits	Stormwater Benefits	Aesthetic Benefits	Total Benefits
American hornbeam	$1.44	$0.07	$0.44	$0.73	$19.99	$22.68
Amur maackia	$2.60	$0.12	$0.81	$1.36	$21.98	$26.87
Amur maple	$2.53	$0.11	$0.82	$0.80	$4.77	$9.03
Baldcypress	$16.07	$0.55	$4.20	$3.22	$32.01	$56.04
Basswood	$3.16	$0.19	$1.02	$1.26	$18.31	$23.94
Blackhaw	$3.64	$0.15	$1.18	$0.96	$4.68	$10.61
Callery pear	$2.08	$0.16	$0.78	$0.99	$16.79	$20.79
Cherry plum	$4.95	$0.21	$1.64	$1.34	$4.89	$13.04
Chinese elm	$1.07	$0.04	$0.33	$0.51	$17.11	$19.08
Cockspur hawthorn	$2.48	$0.10	$0.80	$0.65	$3.83	$7.85
Common chokecherry	$4.19	$0.17	$1.37	$1.12	$4.81	$11.66
Cornelian cherry	$1.90	$0.07	$0.60	$0.50	$3.40	$6.46
Crabapple	$3.10	$0.12	$1.04	$0.86	$4.86	$9.98
Dawn redwood	$3.67	$0.11	$0.72	$0.31	$15.44	$20.25
Dogwood	$1.03	$0.03	$0.31	$0.26	$2.76	$4.39
Eastern hophornbeam	$1.44	$0.07	$0.44	$0.73	$19.99	$22.68
Eastern redbud	$3.58	$0.14	$1.17	$0.95	$4.53	$10.36
Elm, other	$6.79	$0.34	$2.28	$3.15	$30.83	$43.37
English oak	$2.18	$0.09	$0.64	$0.99	$13.00	$16.90

European hornbeam	$2.15	$0.11	$0.66	$1.12	$21.91	$25.96
Flowering dogwood	$1.77	$0.07	$0.56	$0.46	$3.31	$6.17
Ginkgo	$0.24	$0.01	$0.07	$0.08	$1.91	$2.31
Green hawthorn	$2.33	$0.09	$0.75	$0.61	$3.72	$7.50
Hedge maple	$2.95	$0.13	$0.96	$0.93	$5.14	$10.11
Higan cherry	$3.08	$0.12	$1.00	$0.82	$4.12	$9.14
Honeylocust	$4.29	$0.19	$1.37	$1.43	$22.21	$29.49
Japanese snowbell	$0.92	$0.05	$0.28	$0.44	$18.27	$19.96
Japanese tree lilac	$3.07	$0.12	$1.00	$0.81	$4.21	$9.22
Japanese zelkova	$11.75	$0.39	$2.90	$2.06	$28.12	$45.22
Katsura tree	$6.93	$0.30	$2.25	$3.53	$25.07	$38.08
Kentucky coffeetree	$3.67	$0.11	$0.72	$0.31	$15.44	$20.25
Kousa dogwood	$1.49	$0.05	$0.46	$0.39	$3.10	$5.49
Kwanzan cherry	$2.13	$0.08	$0.68	$0.56	$3.45	$6.90
Littleleaf linden	$1.90	$0.14	$0.64	$1.04	$19.60	$23.32
London planetree	$4.02	$0.15	$1.23	$1.66	$14.16	$21.22
Maple, other	$2.82	$0.13	$0.91	$0.89	$5.01	$9.75
Northern hackberry	$9.02	$0.29	$2.12	$1.40	$24.63	$37.45
Northern red oak	$3.00	$0.13	$0.89	$1.36	$14.57	$19.94
Pin oak	$4.57	$0.21	$1.43	$1.90	$16.28	$24.38
Plum, other	$4.07	$0.17	$1.34	$1.09	$4.52	$11.19
Purpleleaf sand cherry	$1.03	$0.03	$0.31	$0.26	$2.76	$4.39
Red horsechestnut	$1.22	$0.05	$0.38	$0.41	$3.29	$5.35
Red maple	$2.10	$0.10	$0.65	$1.09	$21.61	$25.55
Sargent cherry	$1.79	$0.07	$0.57	$0.47	$3.29	$6.18
Sawtooth oak	$5.32	$0.24	$1.65	$2.18	$19.52	$28.92
Scarlet oak	$3.81	$0.16	$1.16	$1.45	$16.23	$22.80
Serviceberry	$2.27	$0.09	$0.73	$0.60	$3.67	$7.35
Silver linden	$0.91	$0.06	$0.29	$0.40	$11.31	$12.98
Striped maple	$2.93	$0.13	$0.94	$0.92	$5.31	$10.22
Sugar maple	$3.00	$0.14	$0.95	$1.14	$9.91	$15.13
Swamp white oak	$4.72	$0.20	$1.44	$1.86	$18.84	$27.06
Turkish hazelnut	$7.45	$0.24	$1.75	$1.15	$21.10	$31.67
Two-wing silverbell	$2.33	$0.09	$0.75	$0.61	$3.72	$7.50
Yellowwood	$2.70	$0.13	$0.84	$1.42	$22.75	$27.83
Citywide Total	$3.10	$0.13	$0.97	$0.99	$10.51	$15.70